reducing substances leading to carbohydrates, and discusses the conditions favourable for such condensations. The energetics of such a system are treated of in this section, and the effects of general or local concentration are considered. The equilibrium point in reversible reactions is shown to be dependent on concentration.

In the concluding section a general reversible reaction is described as a result of which formaldehyde rises in all intense reactions of light upon substances of bio-chemical origin. This reaction in presence of excess of light is an interesting reversal of the process by which all organic matter has been built up from inorganic sources.

The bearing of this process upon the germicidal action of sunlight, and the destruction of living organisms by ultra-violet light, is discussed, and it is pointed out that the simple organic products so formed are incompatible with the life-processes of living organisms, and so lead to their destruction.

Taking such a reaction as travelling in the reverse direction, it is shown that the building up of organic matter from inorganic must have been a necessary precedent to any existence of living organisms on the earth, and that all accumulations of reduced substances possessing stores of chemical energy must have arisen in this manner from storage of the energy of sunlight.

Growth of Trees, with a Note on Interference Bands formed by Rays at Small Angles.

By A. Mallock, F.R.S.

(Received December 1, 1917.)

But little is known about the growth of wood, little that is as to the times and rates at which the growth takes place.

When a tree is cut down, its age and growth in a season can be determined by the number and dimension of the annual rings, at any rate where the annual rings exist and are well marked; though it not infrequently happens that the rings are alternately weak and strong, so that some doubt may arise as to whether there have not been two periods of growth in one year.

Many tropical trees do not show annual rings at all, and in their case the age of the tree and its growth in a year cannot be found from an examination of a section.

It would, I believe, be an assistance in Forestry could some fairly simple means be found for measuring rapidly, *i.e.*, in a few days, or even weeks, the

rate of growth of timber trees; and during the last summer I have made a few trials of such measurements, using an adaptation of an apparatus previously designed for observing the extension of cracks in buildings.

In both trees and building cracks the rate of extension is very small, though much greater in the former than the latter.

The increase in diameter of ordinary timber trees, as shown by the distance between the annual rings, varies largely with the species and the surrounding conditions, ranging from less than 0·1 up to 0·8 inch per year, or say from $\frac{1}{4}$ to $2\frac{1}{2}$ (or more) inches increase of girth. If this growth were continuous and uniformly spread over the year, the increase per hour would be between 0·000028 and 0·00028 inch.

Cracks in old buildings, on the other hand, may spread perhaps only at the rate of an inch in 1000 years or 0·0000001 (or one ten-millionth of an inch) per hour. With a good microscope there is no great difficulty in measuring lengths of 0·00005 inch, so that, as far as magnitudes are concerned, the hourly growth of trees could be quite well determined in this way; but to apply the necessary magnifying power in the position required would in most cases be inconvenient.

If, in place of ordinary optical magnification, interference methods are employed, so that the change in the girth of the tree is measured in terms of wave-lengths, much simpler apparatus will suffice; for in this case the change of the position of interference bands which are visible without, or with very little, magnification takes the place of micrometer measures made with high-power objectives.

There are many ways of producing suitable interference bands, but I will only mention the two which I have actually used. If two flat glass plates, A and B, one of which (say B) has a straight edge, are superposed, so that the straight edge of B rests on the surface of A, and if the surfaces of A and B are slightly inclined to one another, and are viewed by reflected monochromatic light incident normally or nearly so, the field will appear covered with parallel and equidistant light and dark bands, parallel to the edge of B, separated by intervals which are directly proportional to the wave-length of the light, and inversely as the angle between the plates.

If the angle is altered so that the $(n+1)$th band (say) occupies the place formerly held by the nth band, the distance between the plates at that place is altered by half a wave-length (in the case of soda light about the hundred-thousandth of an inch). With suitable means the shift of one-tenth of a band can be recognised, corresponding to an alteration of distance between the plates of a millionth of an inch. This is the plan suitable for detecting the extension of cracks.

For the much more rapid growth of trees, however, it is convenient to use an arrangement which demands a greater variation of angle to cause the same amount of shift in the bands, and this can be secured by merely forming the bands by light having a grazing instead of a normal incidence. For this purpose the plate A is replaced by a right-angled prism. The bands now formed are not equidistant and have several peculiarities which need not be here particularised. The theory is given in the note at the end of this paper. What is of importance for the present purpose is, that the alteration of angle between A and B necessary to shift one band to the position formerly occupied

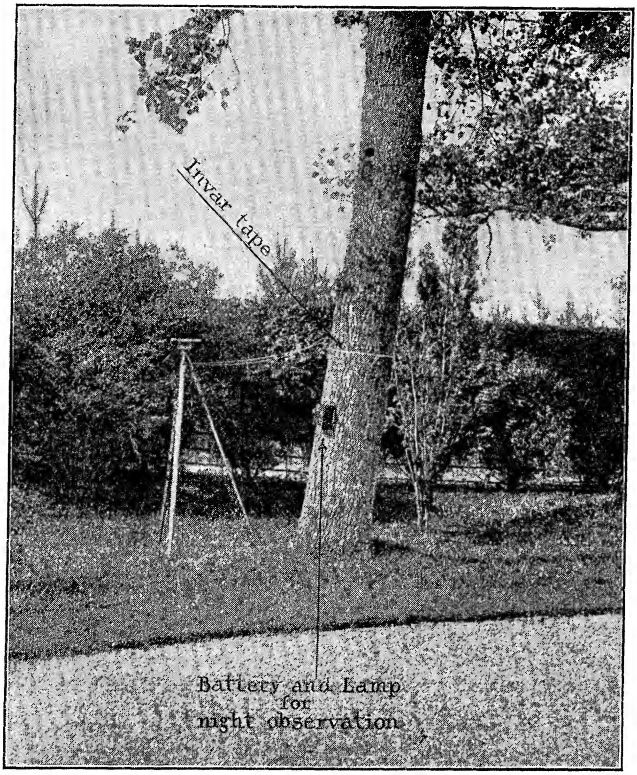

Fig. 1.

by its neighbour is more than ten times as great as when the incidence of the light is normal.

The arrangement for using these bands in the measurement of the growth of trees is shown in figs. 1 and 2. At the place of measurement (usually about 5 feet above the ground) a tape of "invar" is passed round the trunk, the roughnesses of the bark having been previously smoothed with a rasp.

The tape is passed over the rockers R_1, R_2, as in fig. 2,* and is kept in constant tension by the spiral springs S_1, S_2, one of which is hooked on to a ring at the end of the tape, and the other to an adjustable clamp, gripping the tape at an appropriate place. To each rocker an arm is attached, carrying a cylindrical stud, H_1, H_2. Thus any expansion or contraction in the girth of the tree causes the distance between the studs to increase or diminish, the friction between the tape and rockers under the tension of the springs being quite sufficient to prevent slipping.

The optical part of the apparatus (figs. 2 and 3) hangs freely from an

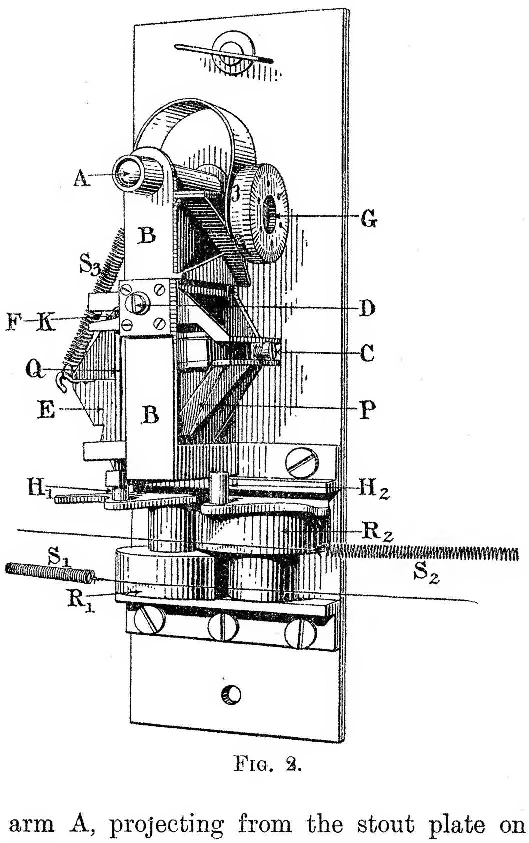

FIG. 2.

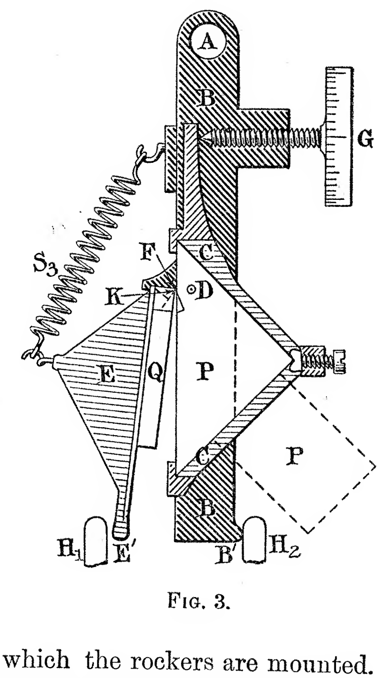

FIG. 3.

arm A, projecting from the stout plate on which the rockers are mounted. The plate itself is attached to the tree trunk by screws. P is a right-angled glass prism mounted on a support C, capable of turning about the axis D in the outer frame B, and the angular position of the prism, with reference to B, can be adjusted by the micrometer screw G. Q is a flat glass plate, blacked on the hind surface, and having a straight edge at F. The plate is

* In fig. 2 the tape is replaced by a thread, so that the rockers may not be hidden from view.

mounted on the stiff support E, and the edge F is kept pressed against the face of the prism by a light spring S_3, which also tends to turn the plate about the edge (and the knife-edges K in line with it) outward from the face of the prism. The distance between E′ and B′ (fig. 3), and therefore the angle between the plate and prism, is limited and defined by the two studs on the rockers, thus any change in the girth of the tree causes a corresponding change in the angle between the two glass surfaces.

When preparing for a set of observations, the bedplate is first secured to the tree, and the "invar" tape is then passed round the smoothed track on the bark and over the rockers, and the tension springs are hooked on to the tape and secured. The prism holder is next put in place, and the two rockers are turned until the studs bring the surfaces of the plate and prism into contact. The interference bands are now very broad (in fact, if the surfaces were truly flat and truly in contact, the field would appear of one uniform shade). The micrometer screw is now turned until the bands assume a width convenient for observation.

In order to define the position of the bands, a narrow central streak M (fig. 4) is painted on the face of the prism with an alcoholic solution of safranin or other suitable anilin colour. This, when dry, is only a small fraction of a wave-length in thickness, but the colour is quite apparent by transmitted light. A narrow gap T is made in the streak by means of a pointed piece of hard wood wetted with alcohol, and this serves as a mark to which the position of the interference bands can be referred. When very small variations of the girth of the tree, such as may occur every few minutes, are to be observed, it is convenient to measure them by estimating the fraction of the band which crosses the gap, but, for ordinary work, where the intervals between the observations are an hour or more, the plan adopted is to bring back the bands to their previous position by turning the micrometer screw, whose readings give directly the variation of angle between the plate and prism which has taken place since the previous observation. Here the optical theory does not enter, and the bands are simply used as delicate callipers.

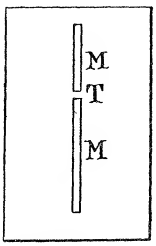

Fig. 4.

To facilitate observation, a second right-angled prism (P′, fig. 3) is cemented to the interference prism so as to reflect the emerging pencils in a horizontal direction to the small telescope, seen in fig. 1, whose aperture is reduced sufficiently to give good definition to the bands.

The first trials of the apparatus were made in April and May, 1917, at Kew, where, by the kindness of Sir David Prain, I was enabled to make observations on several species of trees. It was soon found that the rate of

growth was different in each case, but always greater in the early part of the day than later. In fact, actual contraction was noticed on several occasions between noon and 3 P.M. This showed that there was a considerable daily component involved, but its magnitude could not be determined with any certainty by observations which began at 10 A.M. and ended at 5 P.M.

From June 21 to the end of July, while staying in the country, I made constant observations day and night on four trees, devoting a week or ten days to each. The records so obtained are reproduced in Diagrams I–IV, together with the temperature of the air.

It will be noticed that the increase of girth and the temperature curve are rather closely related, the growth being most rapid when the temperature is lowest, or nearly so. Also that rain has a great effect, any shower being followed by increase of girth.

A probable explanation of these facts may be found in the variable rate of evaporation from the leaves, combined with a nearly constant flow of sap into the roots. Presumably, the mean line through the diagram of girth indicates the rate of formation of new wood, the divergence from the mean representing the degree of turgescence in the bark and layers immediately underlying it.

The effect of rain may be partly mechanical, that is, it may act by merely wetting the bark and thus causing it to swell; at any rate, this may happen in the case of heavy rain, but it must also act by checking evaporation from the leaves, and in the case of light showers this is probably the most efficient factor.

I regret that I had no means of measuring the humidity of the air. In any future trials this should be observed. The daily component, as well as the average growth, varies largely in the different trees, and far more extended observations would be required before any generalisation should be attempted.

The method of measurement, however, is simple and satisfactory, and the results, as far as they go, seem sufficiently interesting to warrant their publication.

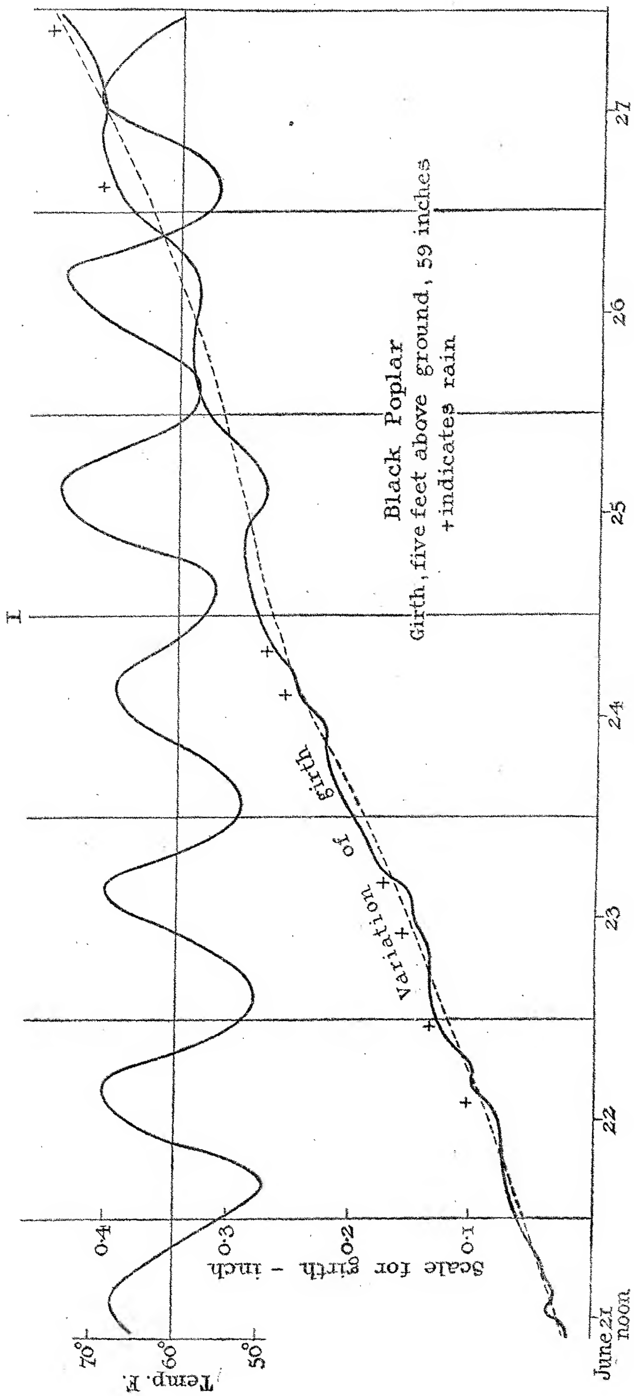
Black Poplar
Girth, five feet above ground, 59 inches
+ indicates rain
Variation of girth
Scale for girth - inch
0·4
0·3
0·2
0·1
Temp. F.
70°
60°
50°
June 21 noon
22
23
24
25
26
27
I

DIAGRAM I.

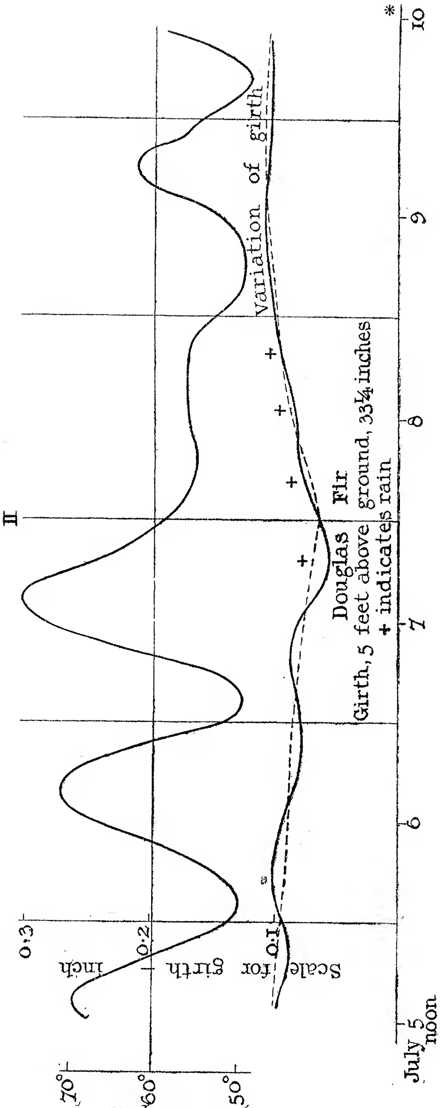

DIAGRAM II.

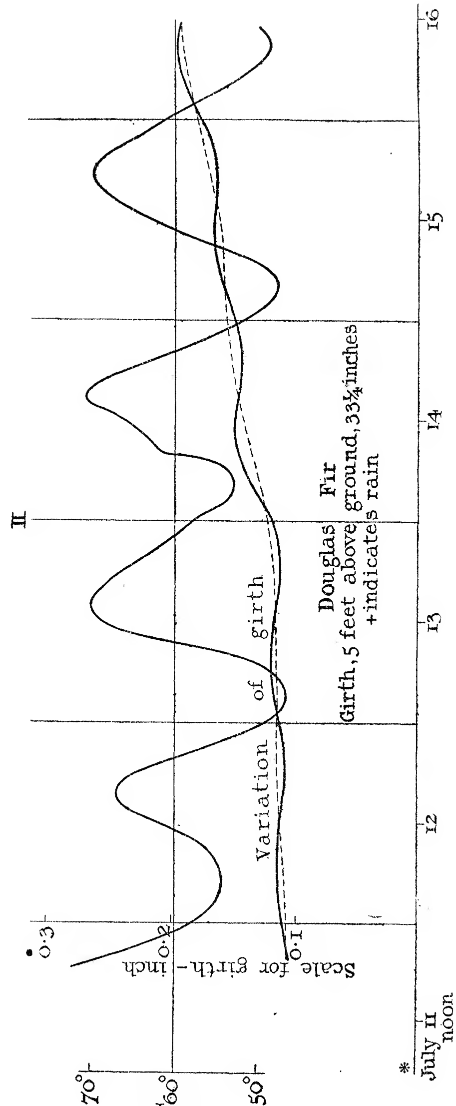

DIAGRAM II—*continued.*

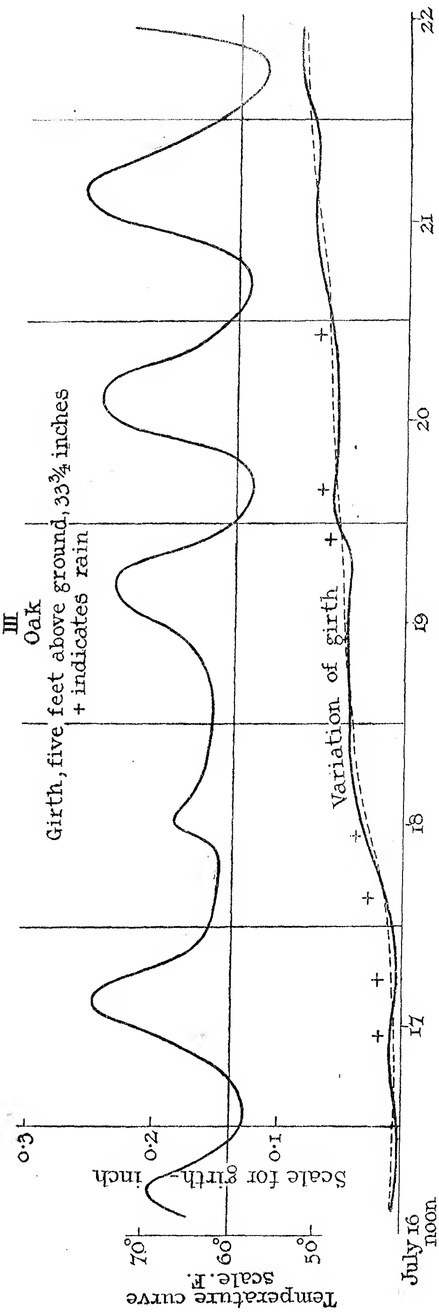
III
Oak
Girth, five feet above ground, 33¾ inches
+ indicates rain
Variation of girth
Scale for girth—inch
0·3
0·2
0·1
Temperature curve
scale. F.
70°
60°
50°
July 16
noon
17
18
19
20
21
22

Diagram III.

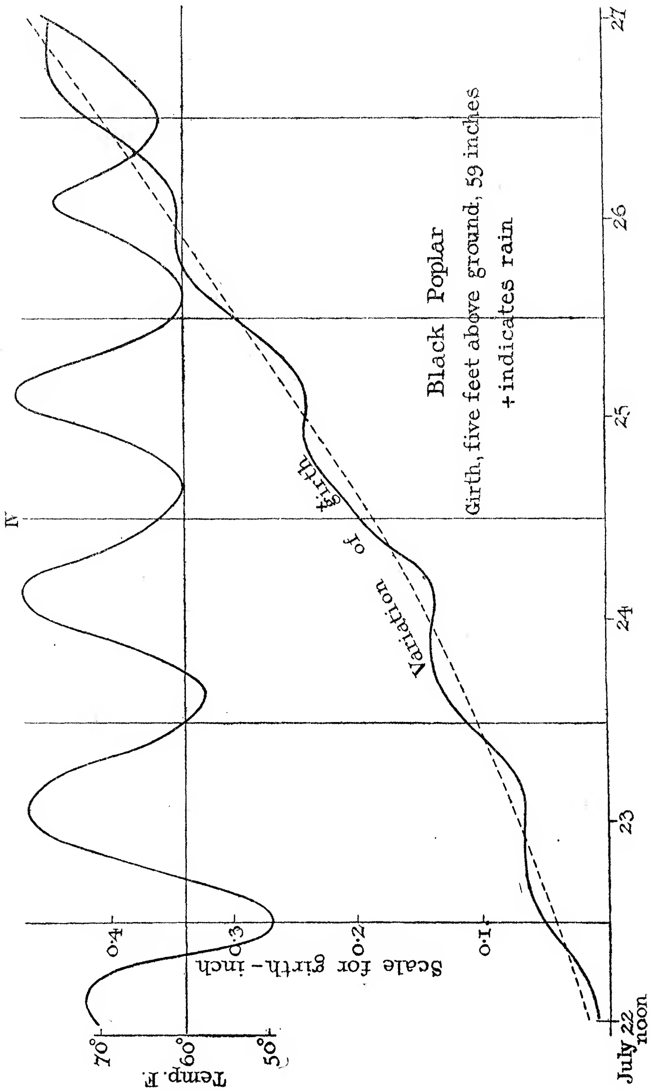

Diagram IV.

Note on Interference Bands Formed by Rays Making Small Angles with the Reflecting Surface.

When light falls very obliquely on flat superposed plates separated by a small interval, no interference bands can be distinguished, owing to the nearly complete reflection which takes place at the first surface and overpowers the weak rays penetrating to, and reflected from, the surfaces where the interference occurs. If, however, a prism is substituted for the upper plate, the 'interference bands, due to rays whose path in the air space

between the surfaces makes a small angle with the surfaces themselves, can be easily observed.

When the angle of emergence (i) from the face of the prism is nearly $\pi/2$, and the angle (r) at which the ray strikes the face internally is therefore, nearly rn^{-1}/μ, a small change in r causes a large change in i.

If $i = 90-\gamma$, so that γ is the angle which the emergent ray makes with the face of the prism, and if e is the difference between r and the angle of total internal reflection (r_0), then $dy/de = (\mathrm{B}+e)/\sqrt{(2\mathrm{B}e)}$, where B stands for $\mu \cos r_0$.

Thus, when $e = 0$, $dy/de = \infty$. This has an important effect on the positions and appearance of the interference bands.

Below the face of the prism (fig. 5) let there be a flat glass plate touching the face at O, and inclined to it at a very small angle α. Take O as the origin, and the face of the prism as containing the axis of x; then the distance y between the two surfaces at x is αx.

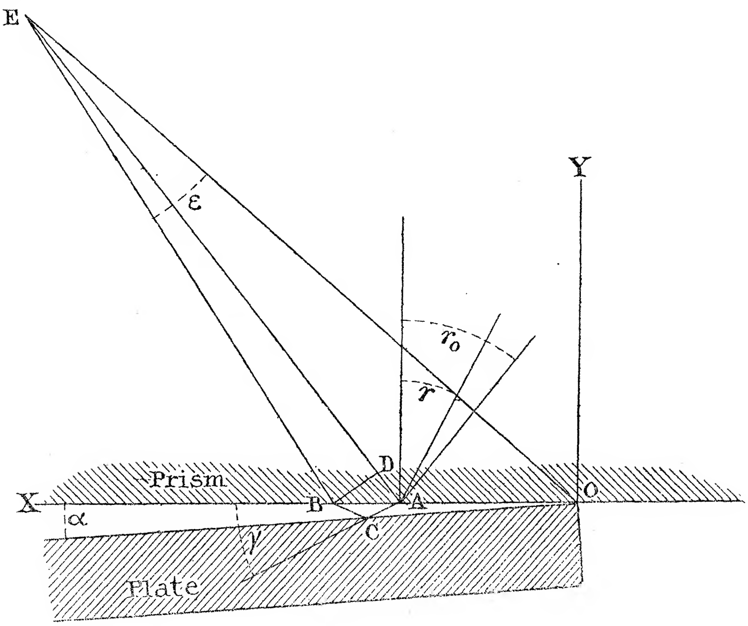

Fig. 5.

If a ray within the prism strikes the surface at A, making an angle r with the axis of y, the transmitted part makes an angle γ with the face, and, being reflected from the lower plate, again enters the prism in a direction hardly differing from r (on account of the smallness of α). It is then in a condition to interfere with the ray reflected from the prism surface at its point of entry. The optical lengths of the paths of the interfering rays are

respectively AC + CB in air, and μAD in glass. The difference in their length is easily shown to be equal to $2y\gamma$.

Let the surfaces be viewed from a point E at a distance L from X; then, noting that OEB $= e$, and writing B for $\mu \cos r_0$, it will be found that $Y = \sqrt{(2X/\mu L)}$, and that, consequently, the relative retardation of the interfering rays is $2aBX\sqrt{(2x/\mu L)}$.

Taking into account the half-wave-length change of phase at the internal reflection at B, the bands are bright or dark, according as the retardation is $n\lambda$ or $\frac{1}{2}(2n+1)\lambda$.

Hence for the bright bands $x = \left(\dfrac{n\lambda}{2aB}\right)^{\frac{2}{3}} (\mu L)^{\frac{1}{3}}$

for the dark bands $x = \left(\dfrac{2n+1}{4aB}\lambda\right)^{\frac{2}{3}} (\mu L)^{\frac{1}{3}}$

so that their spacing is not uniform.

These bands differ in several other ways from those formed by normal, or nearly normal, incidence. The latter practically have an objective existence at the surfaces of interference, and can be viewed by a telescope adjusted to focus an object at the distance of the plate from the observer, the reason being that the size and position of the bands change only slowly with the angle of incidence. In the case at present under consideration this condition does not hold. As Stokes* puts it:—

> "When the angle of incidence becomes nearly equal to that of total reflection, a small change of obliquity produces a great change in the order of the ring to which the reflected ray belongs, and therefore the rings are indistinct to an eye adapted to distinct vision of the surface of the glass. They are also indistinct, for the same reason as before, if the eye be adapted to distinct vision of distant objects. To see distinctly the rings in the neighbourhood of the angle of total internal reflection, the author used a piece of blackened paper, in which a small hole was pierced with the point of a needle."

Stokes is here speaking of Newton's rings. In the case of bands between flat plates, the aperture of the pupil need not be limited, if the observation be made at a distance of some feet.

Another peculiarity of these bands may be mentioned. When formed by white light, the bands are, of course, coloured. For those distant from the line of total reflection the blue is on the inside, *i.e.*, nearest to that line, but, for the band close to the line, the blue is on the outside. Between them occurs a band which appears achromatic. The explanation is

* Stokes, 'Collected Papers,' vol. 2, p. 359, from 'B.A. Report,' 1850.

shortly as follows: As has been stated, the relative retardation of the interfering rays is $2y\gamma$. Here γ (and in a less degree y) varies with μ, and with the wave-length. If two rays, say, yellow and blue, are to reach the eye in the same direction and with the same relative retardation, then must $y_Y\gamma_Y/\lambda_Y = y_B\gamma_B/\lambda_B$. The difference between y_Y and y_B is small compared

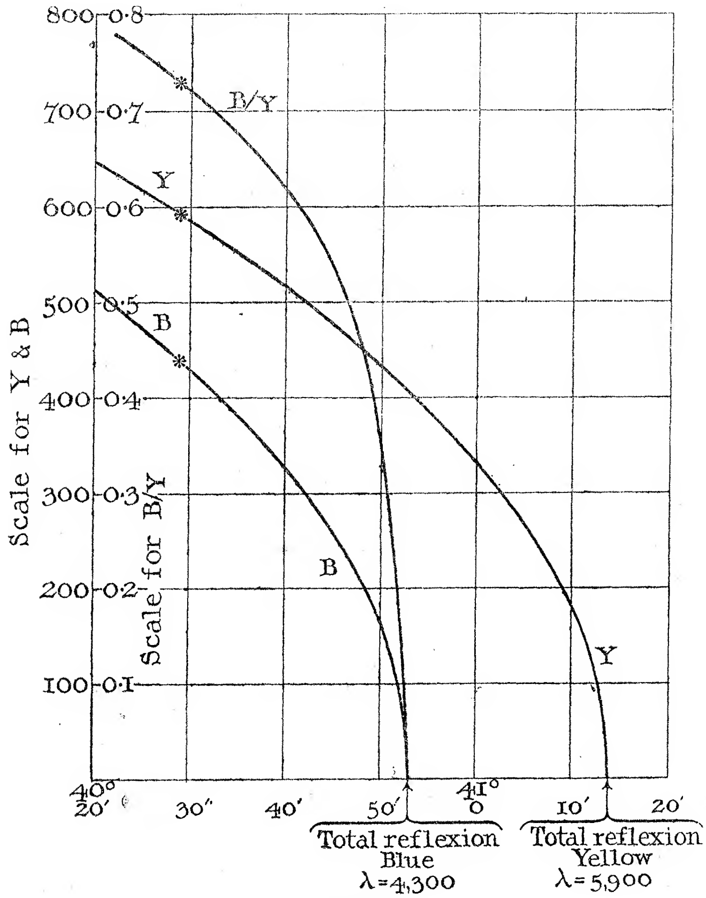

FIG. 6.

to the difference between γ_Y and γ_B, and therefore there is approximate achromatism when $\gamma_Y/\gamma_B = \lambda_Y/\lambda_B$.

The diagram (fig. 6) will make this clearer. The two curves Y and B (which relate to a sample of crown-glass) give the value of γ in terms of r, in the neighbourhood of the angle of total internal reflection, Y referring to the yellow of the D line, and B to the blue near G, viz., at $\lambda_Y = 5900$ and $\lambda_B = 4300$.

It will be seen that there is one value for r (marked by * on the figure)

and one only, which makes $\gamma_B/\gamma_Y = \lambda_B/\lambda_Y = 0{\cdot}73$, viz., when $r = 40° \; 29'$ (45′ less than the angle of total reflection for the yellow and 24′ less than for the blue).

At the position so defined there will be a band with borders only faintly coloured. On either side of this band the order in which the colours appear will be reversed.

On the Efficiency of Muscular Work.

By M. Greenwood, Captain R.A.M.C. (T.F.), Lister Institute of Preventive Medicine.

(Communicated by Prof. Leonard Hill, F.R.S. Received January 18, 1918.)

In a paper communicated to the Royal Society in 1913,* Prof. J. S. Macdonald published a series of observations upon the heat production of persons performing certain known quantities of work upon a bicycle ergometer. In that paper, and again in a more recent publication,† Prof. Macdonald has outlined certain methods of interpreting his results, which are of much importance; these I shall discuss in the latter half of this communication, but, before doing so, it will be interesting to examine some purely numerical questions to which Macdonald's paper gave rise.

In a note on Macdonald's earlier paper, Messrs. Glazebrook and Dye‡ have published a formula descriptive of Macdonald's numerical results. This formula is

$$H = a + bM + \frac{W}{\alpha + \beta M}, \qquad (1)$$

where H = heat production in calories, M = body mass in kilogrammes, W = work equivalent in calories, a, b, α, and β are constants.

The values of the constants, which were obtained by a graphical process led in the particular case to the equation

$$H = -138 + 4{\cdot}5M + \frac{W}{0{\cdot}08 + 0{\cdot}003M}, \qquad (2)$$

and this equation was found to provide values in very fair agreement with the observed results.

It will be noticed that, when the body weight is constant, the heat production

* 'Roy. Soc. Proc.,' B, vol. 87, p. 96 (1914).

† *Ibid.*, vol. 89, p. 394 (1917).

‡ *Ibid.*, vol. 87, p. 311 (1914).

Fig. 1.